2003 AFCEE Technology Transfer Workshop
San Antonio, Texas
Promoting Readiness through Environmental Stewardship

SIMULATION/OPTIMIZATION TOOLS FOR ROBUST PUMPING STRATEGY DESIGN

R. Peralta I. Kalwij
AFRPA/EV SAF/IEI USU
FEB 2003

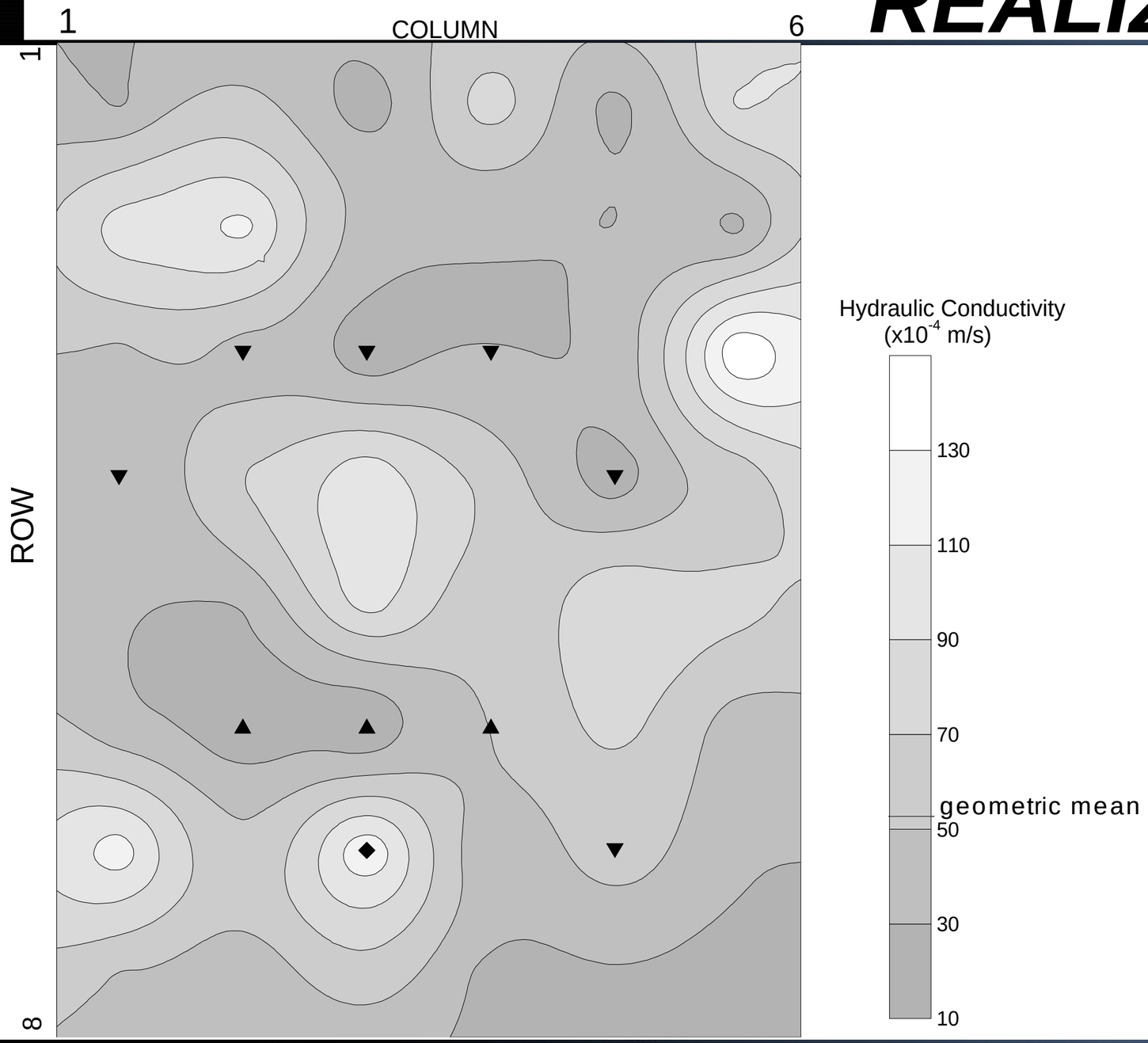
INTRODUCTION

- **The goal is to demonstrate tools for developing more robust optimal pumping strategies**
- **A pumping strategy is a spatially and perhaps temporally distributed set of pumping rates.**
- **Simulation/Optimization models compute mathematically optimal pumping strategies.**
- **SOMOS is an extremely powerful SO model.**

ALTERNATE REALITIES AND 'REALIZATIONS'

- **Differences between field and model can occur in all assumed parameters, including boundary conditions.**
- **One set of assumed parameters is termed a 'realization'. A realization is an assumed 'reality'.**
- **Realizations can be developed:**
  - **by calibration,**
  - **by user knowledge,**
  - **via statistics (probability distribution function)**

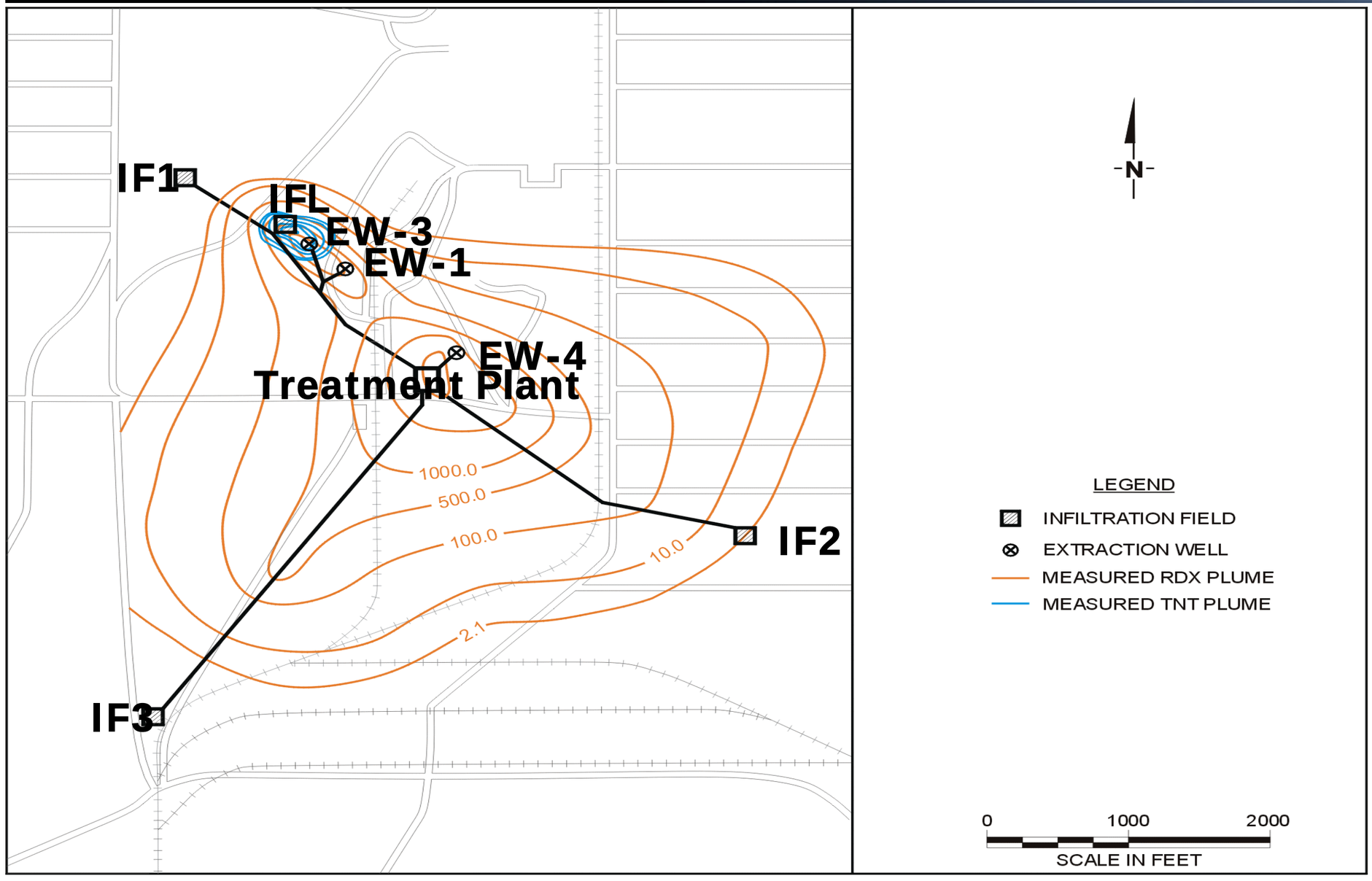
ONE HYDRAULIC CONDUCTIVITY REALIZATION



PUMPING STRATEGIES AND ROBUSTNESS

- **A ‘robust’ pumping strategy will achieve management goals even if the physical system differs from the model.**
- **Robustness is determined by systematically changing model assumptions and using the strategy to run a simulation for each.**
- **A strategy’s K robustness range is the range of K multipliers for which the strategy will satisfy all constraints.**

CONCENTRATIONS BEFORE PUMPING



(Modified from Minsker et al, 2003)

OPTIMIZATION PROBLEM

MINIMIZE COST

Subject to:

- Maximum RDX Year-N Cleanup Zone Conc.
  ≤ 2.1 ppb
- Maximum TNT Year-N Cleanup Zone Conc.
  ≤ 2.8 ppb
- Maximum RDX Forbidden Zone Conc.
  ≤ 2.1 ppb for 20 years
- Maximum TNT Forbidden Zone Conc.
  ≤ 2.8 ppb for 20 years
- Σ |Extraction| ≤ 1170 gpm
- Σ |Extraction| = Σ Injection
- Bounds on Pumping at Individual Wells

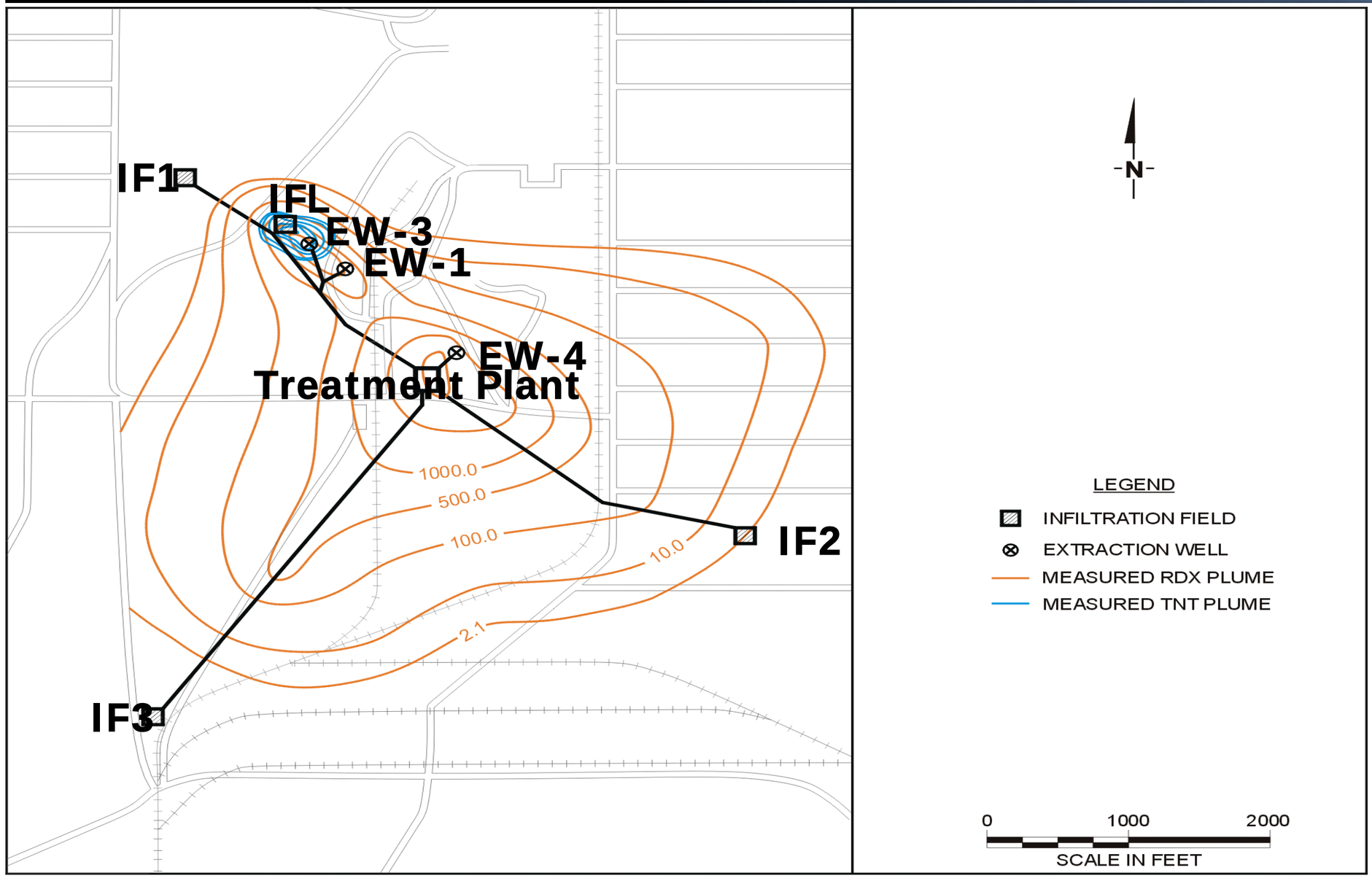
OPTIMIZATION PROBLEM

- **COST =**
  (CCW + CCB + CCG + FCL + FCE + VCE + VCG + VCS)

Where all below costs are discounted:

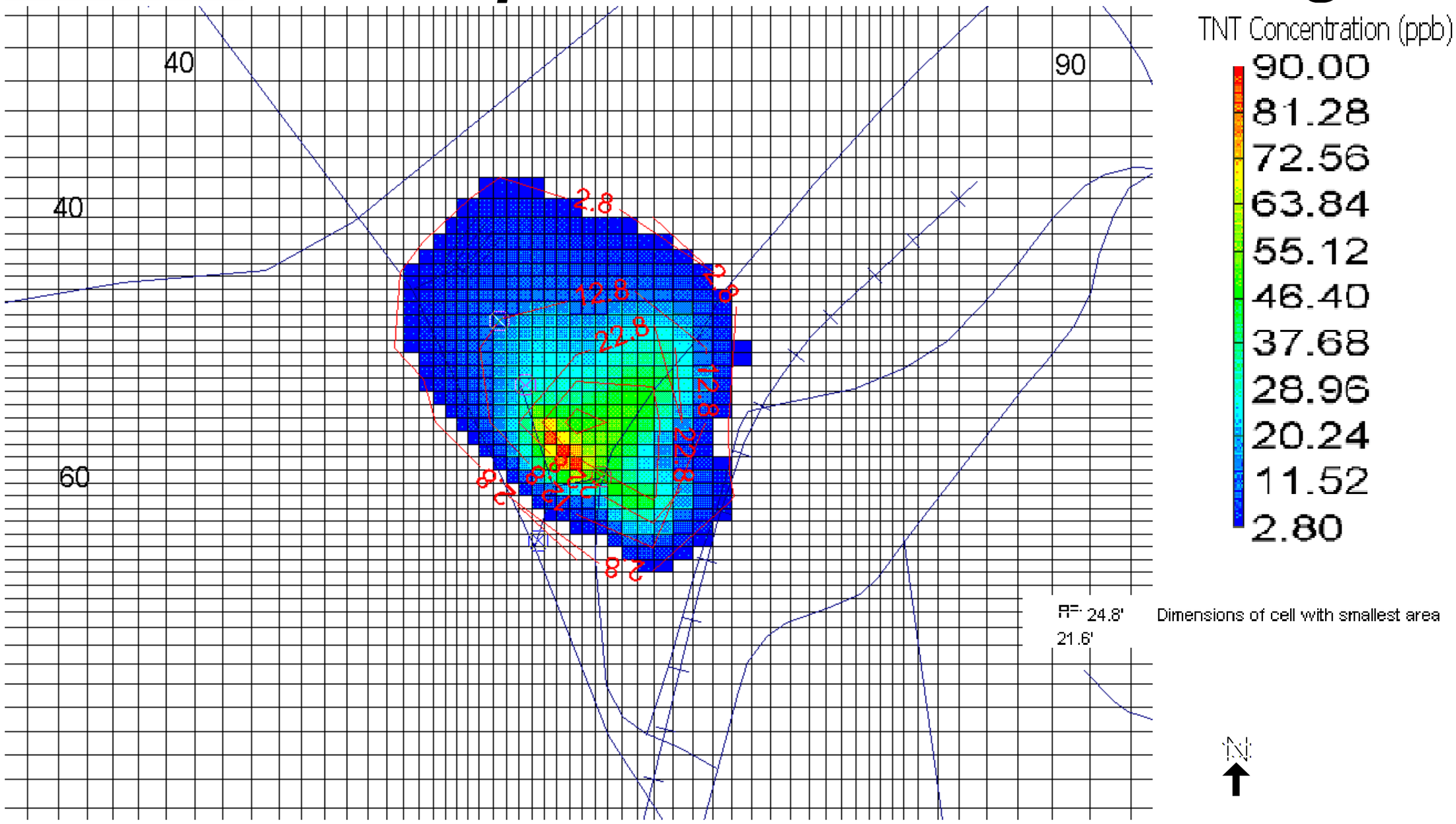
- **CCW = New well capital cost ($75K)**
- **CCB = New recharge basin capital cost ($25K)**
- **CCG = New GAC unit capital cost ($150K)**
- **FCL = Fixed annual labor cost ($237K)**
- **FCE = Fixed annual electricity cost ($3.6K)**
- **VCE = Variable annual electrical cost ($11.7K for 1170gpm)**
- **VCG = Variable GAC change cost (small)**
- **VCS = Annual sampling cost ($150K, yrs 1-5)**

CONCENTRATIONS BEFORE PUMPING

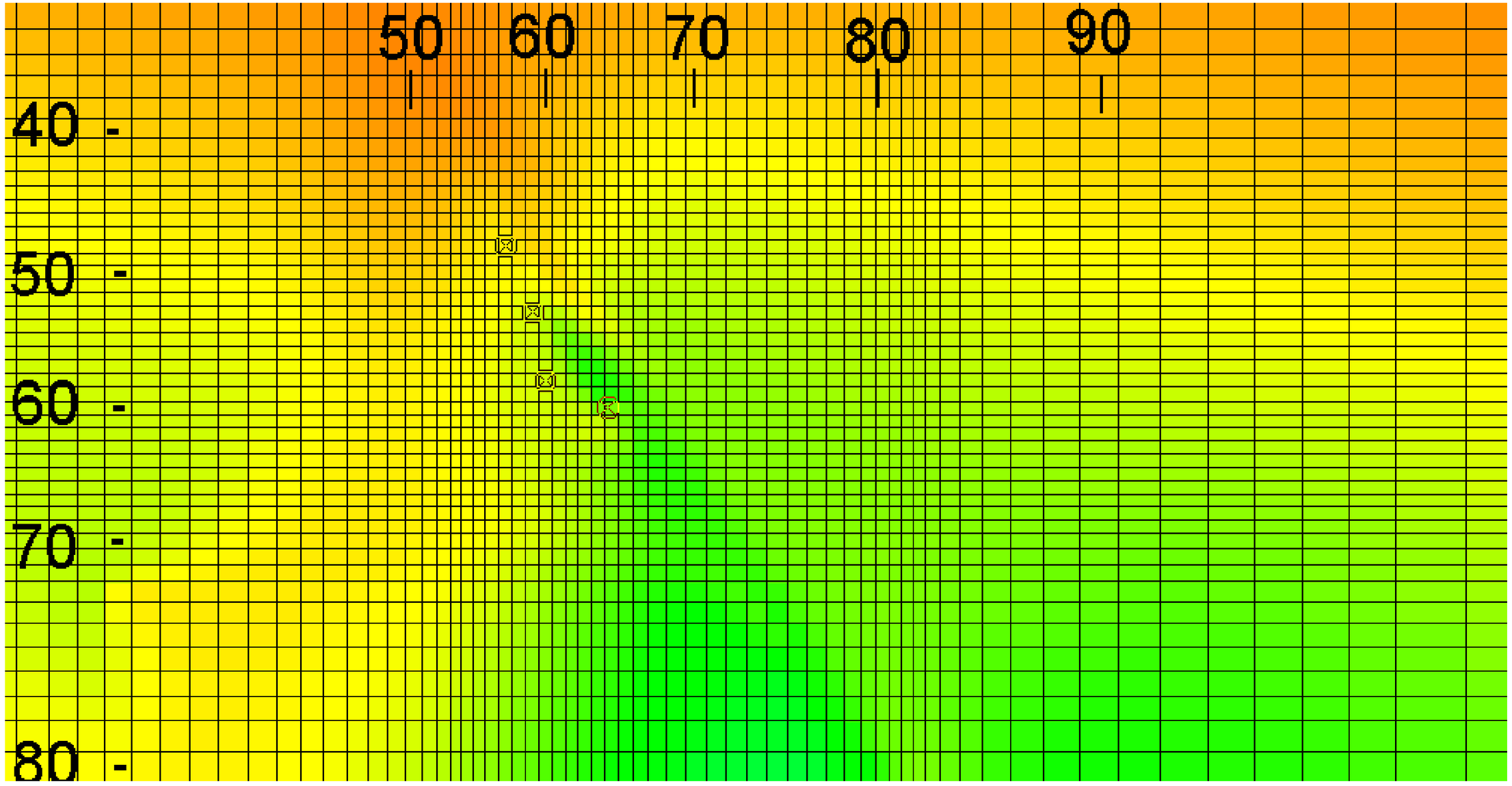


(Modified from Minsker et al, 2003)

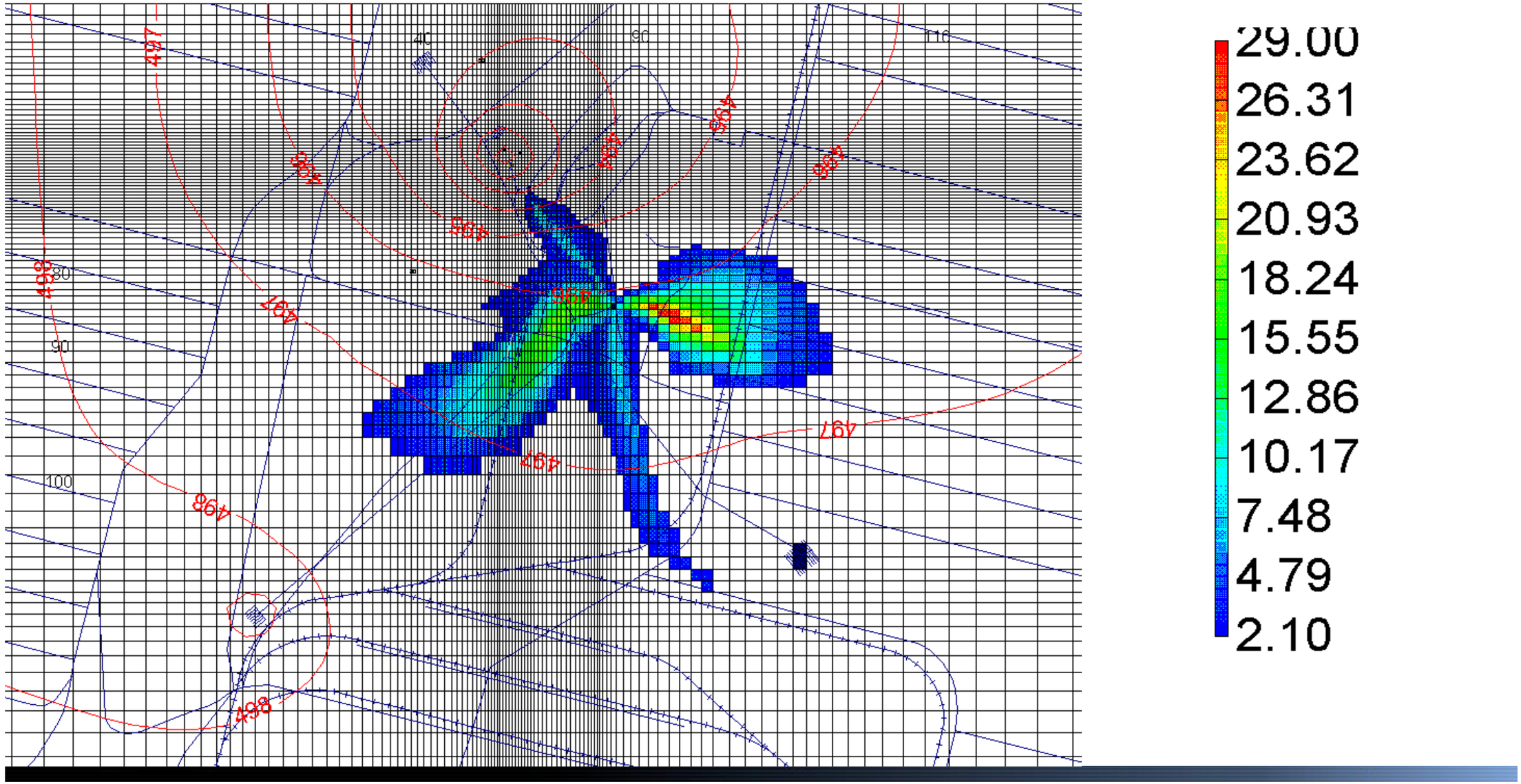
Initial (Jan 2002) TNT ≥ 2.8 ppb, & part of finite difference grid



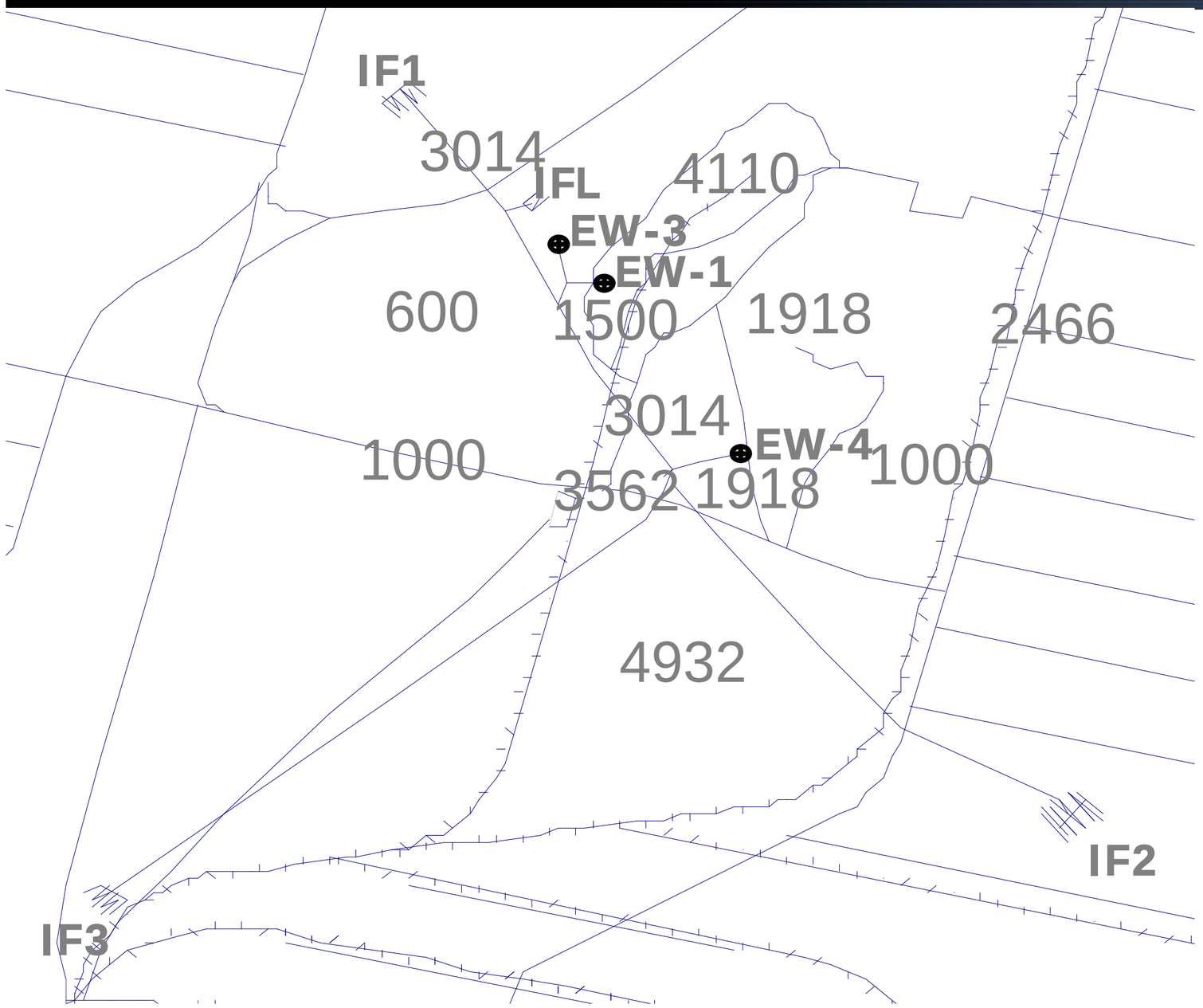
LAYER 1 BOTTOM ELEVATION & WELLS U-1, EW-3, & EW-1



INITIAL RDX ≥ 2.1 PPB & STEADY HEADS AFTER PUMPING PER USU STRATEGY



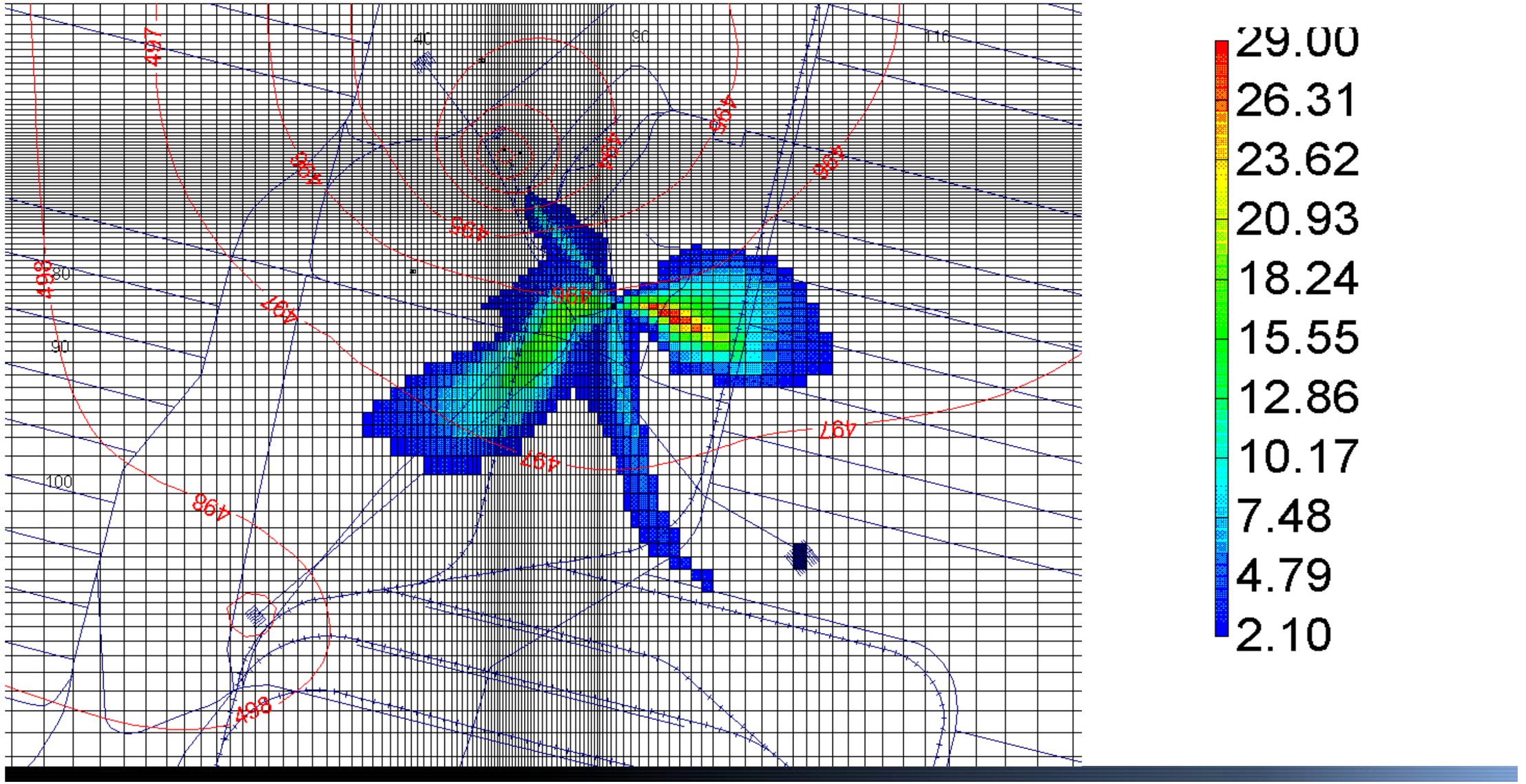
HYDRAULIC CONDUCTIVITY



Hydraulic Conductivity (ft/day)

- 1
- 600
- 1000
- 1500
- 1918
- 2466
- 3014
- 3562
- 4110
- 4932

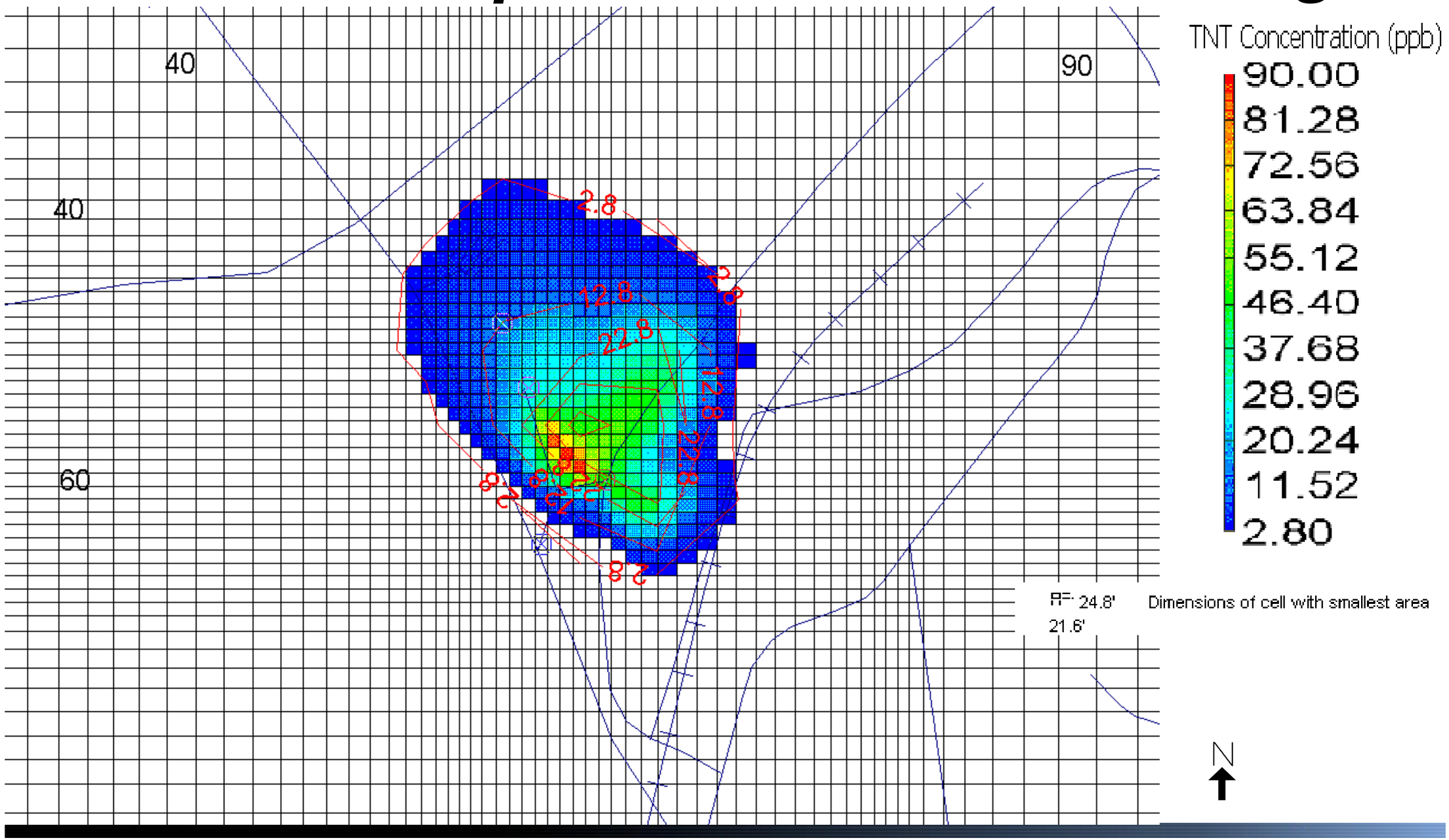
INITIAL RDX ≥ 2.1 PPB & STEADY HEADS AFTER PUMPING PER USU STRATEGY



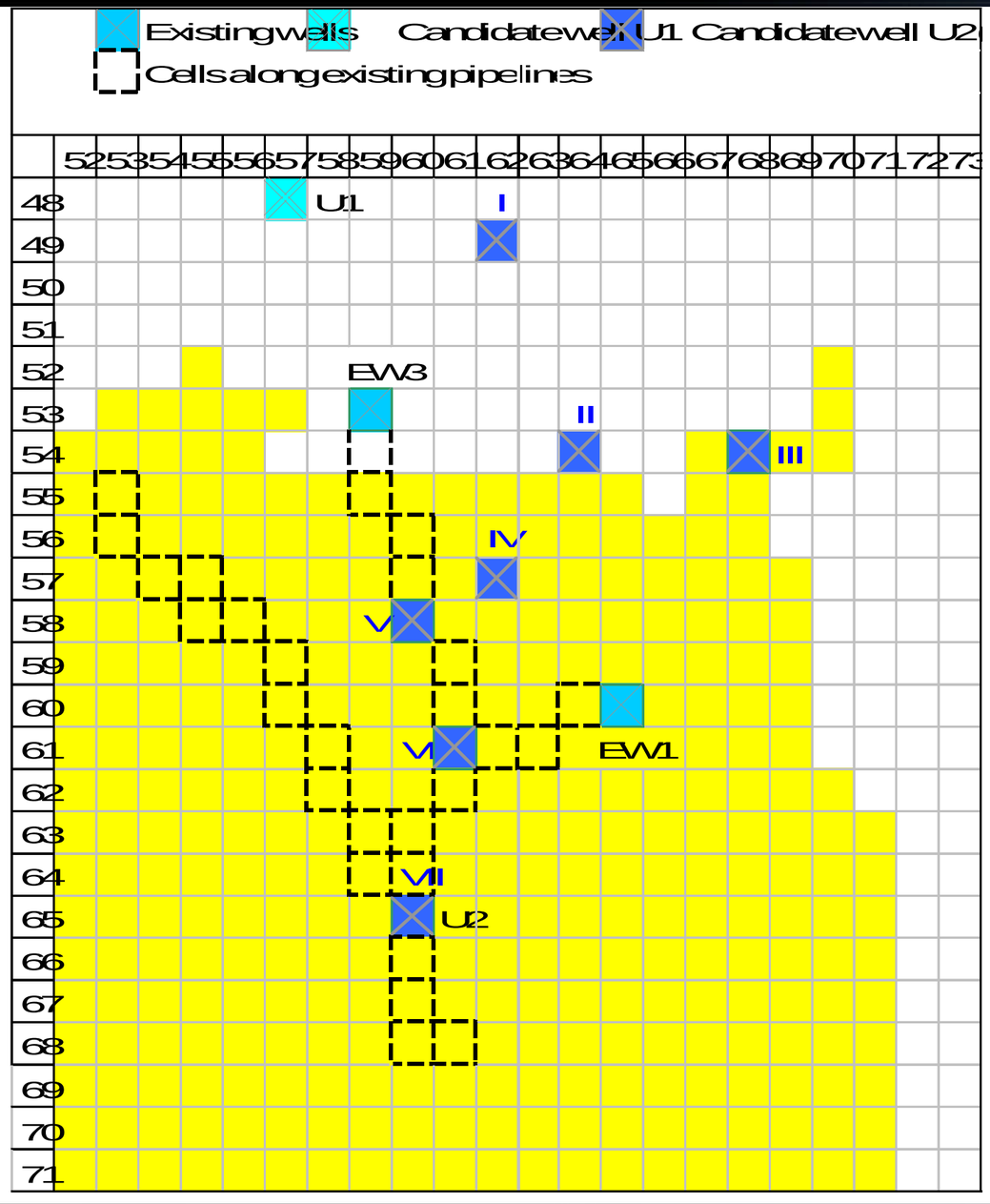
USING OP0 TO DETERMINE ROBUSTNESS RANGE

- Evaluate strategies for remediating Umatilla Chemical Depot RDX and TNT plumes.
- Strategies use:
  - 2 existing injection basins IW2 & IW3
  - 2 existing extraction wells EW1 & EW3
  - 2 candidate extraction wells

Initial (Jan 2002) TNT ≥ 2.8 ppb, & part of finite difference grid



FEASIBLE WELL LOCATIONS



YELLOW CELLS ARE SOME OF THE WELL U2 LOCATIONS THAT YIELD FEASIBLE STRATEGIES.

DARK BLUE CELLS ARE U2 LOCATIONS FOR WHICH ROBUSTNESS IS EVALUATED

SOMO3 OPERATION OP0

Performs robustness analysis automatically for user-specified:

- **strategies, and**
- **realizations**

STRATEGY ROBUSTNESS RANGE EVALUATION (ROBUSTNESS.OUT)

Strategy 1: feasible range

Realizations:	MR2	MR3	MR4	MR5	MR6	MR7	MR8	MR9	MR1	MR10	MR11	MR12	MR13	MR14	MR15	MR16	MR17
Multiplier:	0.84	0.86	0.88	0.9	0.92	0.94	0.96	0.98	1	1.02	1.04	1.06	1.08	1.1	1.12	1.14	1.16

Sim# Well	U2	----																
49	62	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
54	64	2	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
54	68	3	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
57	62	4	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
58	60	5	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
61	61	6	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
65	60	7	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1

INCREASING A STRATEGY'S ROBUSTNESS RANGE

- One strategy, using (58,60) for U2, has a robustness range of -14% to + 6%.
- Assume one prefers to increase the range at least ± 14%
- One can achieve this using the multiple realizations approach

Multiple Realization Formulation

- **Objective Function**
  - **Constraint equations for realization number 1**
  - **Constraint equations for realization number 2**
  - •
  - •
  - •
  - **Constraint equations for realization number N**
- **Bounds on variables**

SOMO3 OPERATION
OP2 (STOCHASTIC)

Automatically develops optimal strategies that satisfy multiple user-input realizations

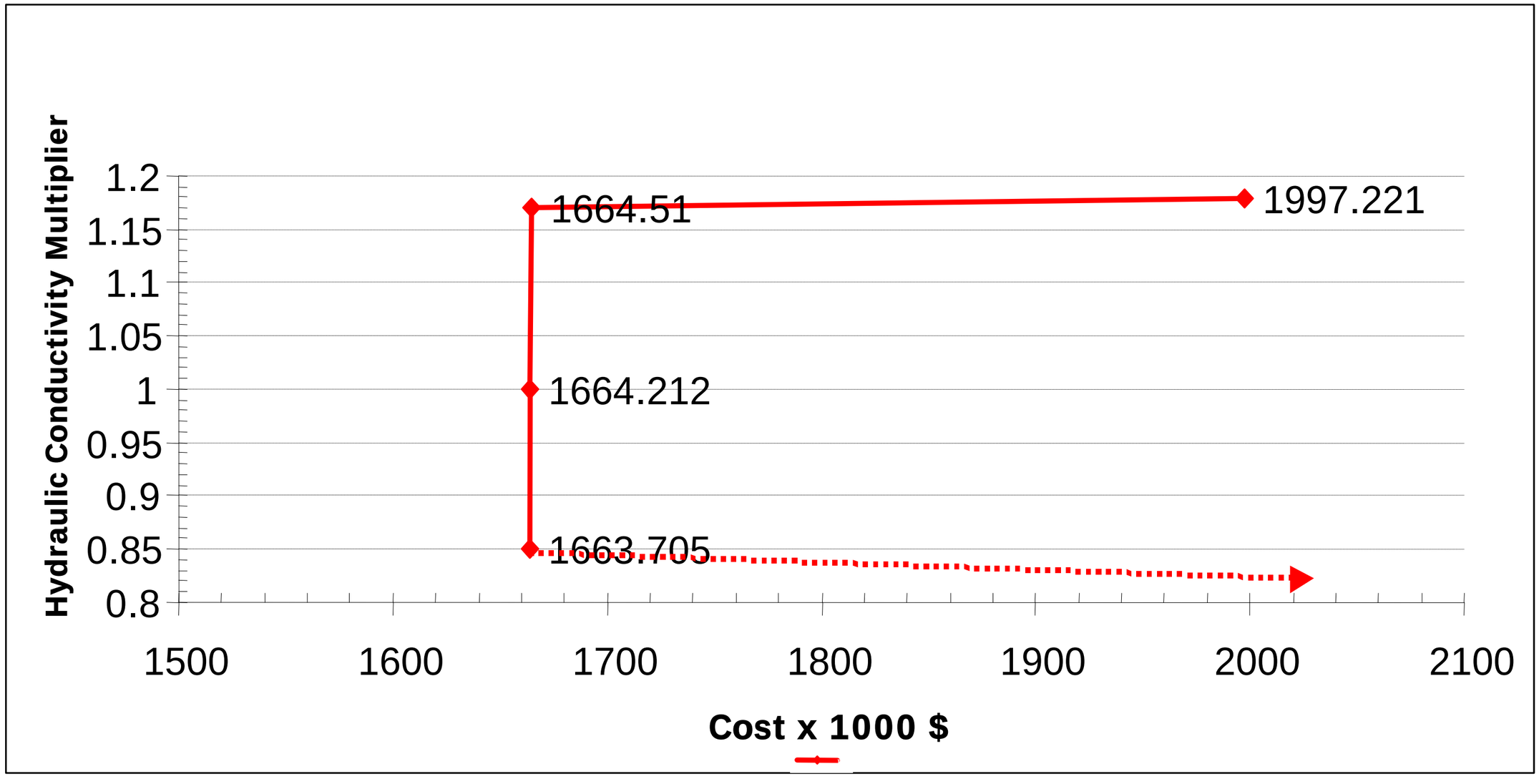
INCREASING ROBUSTNESS RANGE

Realizations:	MR2	MR3	MR4	MR5	MR6	MR7	MR8	MR9	MR1	MR10	MR11	MR12	MR13	MR14	MR15	MR16	MR17
K multiplier:	0.84	0.86	0.88	0.9	0.92	0.94	0.96	0.98	1	1.02	1.04	1.06	1.08	1.1	1.12	1.14	1.16
Initial infeasible strtgy	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Interm infeasible strtgy	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Interm optimal strtgy	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Final optimal strategy	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

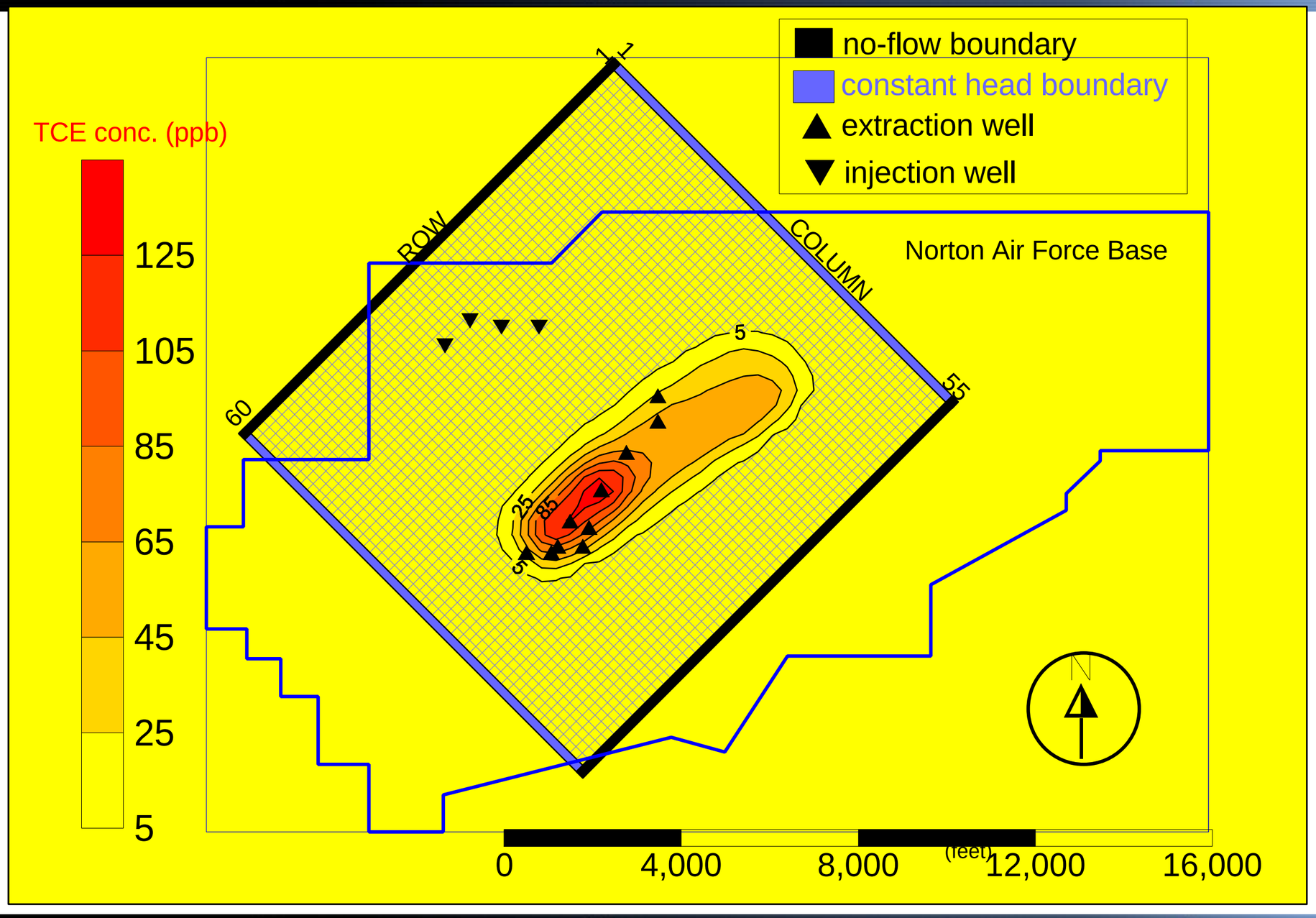
TO INCREASE ROBUSTNESS

- Reduce injection at IW2
- Increase injection at IW3
- Reduce extraction at EW1, EW3, and U1
- Increase extraction at U2

STRATEGY WITH WELL U2 @ (58,60): COST VS K MULTIPLIER

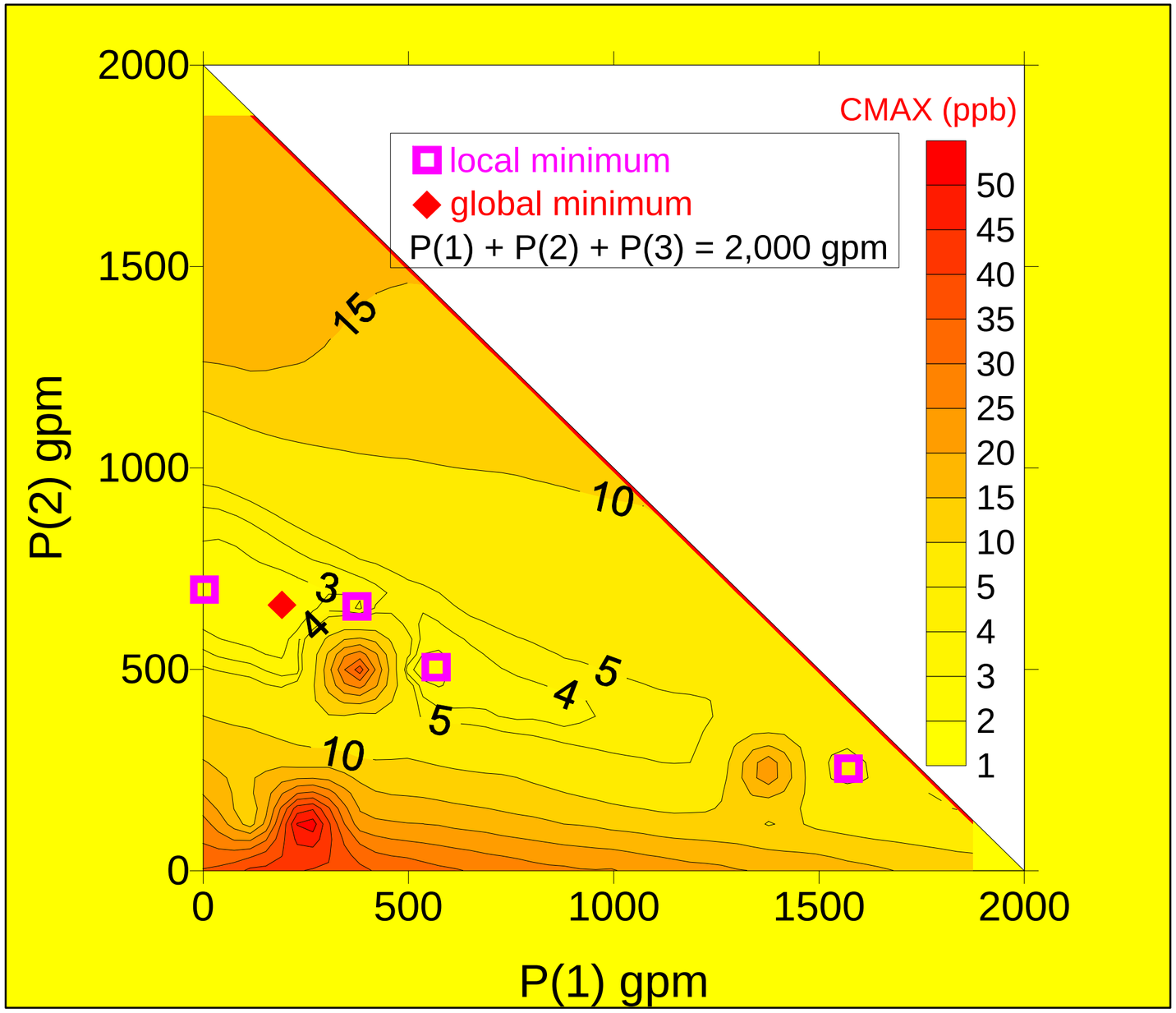


Study Area



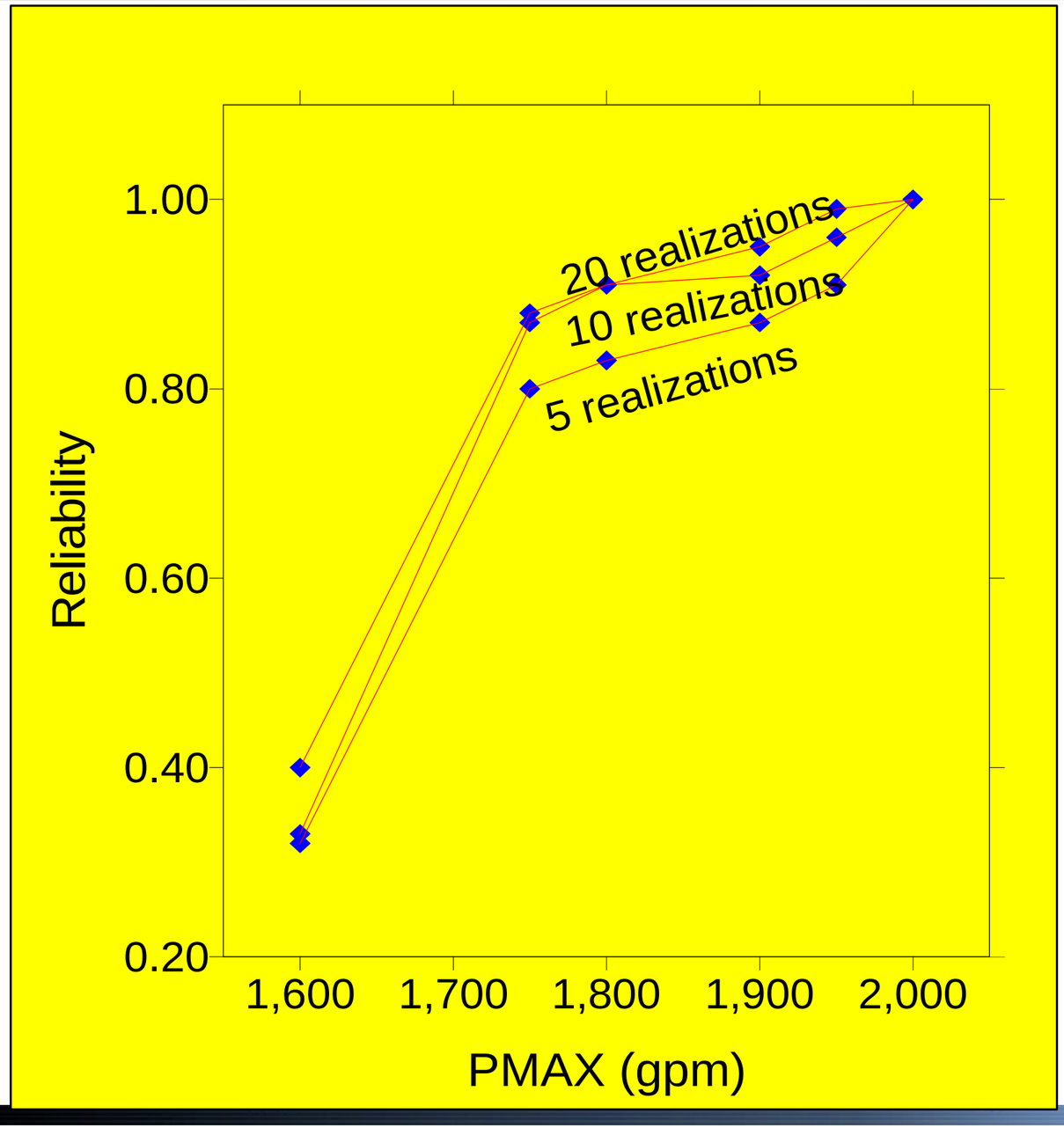
(From Aly and Peralta, 1999)

$CMAX_{(5)}$ (3 wells & 5 realizations)



(From Aly and Peralta, 1999)

Reliability Design Curves (5-well design)



(From Aly and Peralta, 1999)

SUMMARY

SOMOS makes it easy to:

- **Estimate pumping strategy robustness and reliability with respect to aquifer parameter variability**
- **Use multiple realization stochastic optimization to develop strategies for user-selected robustness or develop more reliable strategies**